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Microsurgical Anatomy and Operative Technique for Extreme Lateral Lumbar Disc Herniations

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Summary

The anatomy of the lateral aspect of the lumbar spine and our lateral microsurgical technique for extreme lateral lumbar disc herniations (ELLDH) is described. This study was based on the microdissection of 4 cadavers, on the morphometric evaluation of these as well as 6 dried cadaver spines and 8 lumbar CT scans, and on the use of this technique on over 200 cases.

Level dependent changes in the posterior arch cause a shift of the disc space distally relative to the facet joint, an increasing amount of bone to overlie the intervertebral foramen, and a decreasing amount of working space within the exposure in the caudal direction. Therefore, more bone removal from the lateral aspect of the pars interarticularis and supero-lateral aspect of the facet joint is required in the lower lumbar spine. When the exposed ligamentum flavum is resected, the dorsal root ganglion is seen and access to the herniation and disc space is achieved. Level dependent changes in the pedicles and transverse processes lead to an alteration in the course and relationships of the nerves, thereby influencing the pathophysiology of and surgical technique for the ELLDH. The operative target is the lateral aspect of the pars interarticularis and not the intertransverse space as has been previously described.

Our techniques allows for the early identification of the nerve with minimal risks of injury to it, to the adjacent vessels and to the structural integrity of the facet joint and pars interarticularis.

Keywords: Extreme lateral lumbar disc herniation; far lateral lumbar disc herniation; foraminal disc herniation; extraforaminal disc herniation; intervertebral foramen; lateral interpedicular compartment.

Abbreviations

DRG	dorsal root ganglion
ELLDH	extreme lateral lumbar disc herniation
ESA	erector spinae aponeurosis
ITL	intertransverse ligament
L	lumbar
LA	lumbar artery
LF	ligamentum flavum
LIPC	lateral interpedicular compartment
m.	muscle
S	sacral
TP(s)	TP(s) transverse process(es)

Introduction

An extreme lateral lumbar disc herniation (ELLDH) migrates laterally and often cranially into the intervertebral foramen-"foraminal" herniation- and/or lateral of it "extraforaminal" herniation-[9, 10, 19, 28].

Operative techniques for ELLDH have ranged from an interlaminar approach, with a total or subtotal facetectomy, to various lateral approaches[2, 8, 9, 10, 13, 14, 18, 19, 23, 25, 26, 28, 32]. The paraspinal approach to the lumbar spine has been well described[29, 30]. This paper details the anatomical features that relate to the pathophysiology of and surgery for ELLDH. The lateral microsurgical technique which we have used in over 200 cases is described.

Materials and Methods

Microsurgical dissection was performed in 3 formalin fixed and 1 fresh cadaver bilaterally via paramedian incisions from LI to the sacrum. There were 2 male and 2 female adult cadavers without spinal pathology. Morphometric evaluations of these specimens and of 6 dried cadaver spines and 8 lumbar CT scans were performed with a protractor and calipers. The age, origin and medical conditions of the source of the dried specimens and CT scans was not known. Observations from the dissections and operative cases were recorded with a Pentax camera via the microscope and with drawings.

Results

Since the "intervertebral foramen" is a 3 dimensional area demarcated primarily by the pedicles, we call it the lateral interpedicular compartment (LIPC). The boundaries of the LIPC are demonstrated in Figs. 3, 6 A, 7 C. Structures enter and exit via its medial and lateral "foramina". An ELLDH and some of the anatomy presented in this paper are seen in Fig. 1.

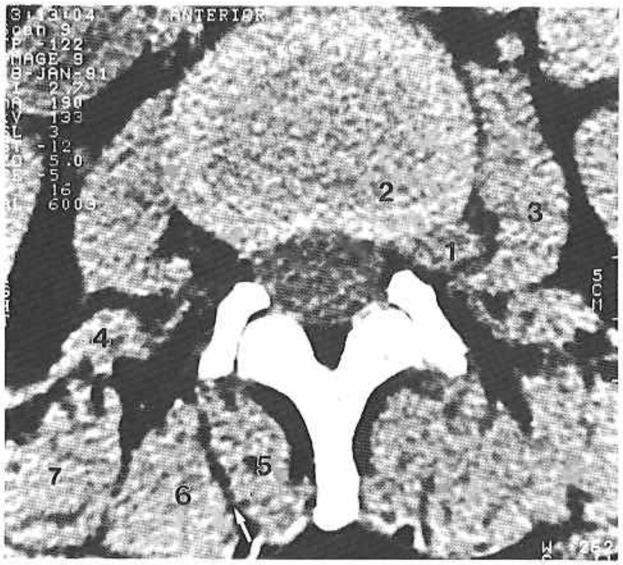


Fig. 1. CT scan of a L 4 – 5 "extraforaminal" herniation. Disc fragment (*1*) in continuity with the postero-lateral aspect of L 4 – 5 disc (*2*), psoas muslce (m) (*3*), intertransverse m. (*4*), multifidus m. (*5*), longissimus m. (*6*), iliocostalis m. (*7*), intermuscular plane for trans-muscular approach (arrow)

Anatomy of the Paravertebral Muscles and Fasciae

Between the cross-hatched posterior layer of the thoracolumbar fascia and the longitudinally orientated fibers of the erector spinae aponeurosis (ESA) was a thin layer of adipose tissue (Fig. 2). The lumbar erector spinae muscles, laterally, and multifidus muscle, medially were immediately ventral to the ESA (Figs. 1, 2, 4 A). The lumbar erector spinae are composed of the lumbar fibers of the longissimus thoracis, medially, and the iliocostalis lumborum, laterally (Figs. 1 and 2)[4]. Progressively ventral and lateral to the multifidus were the intertransversarii mediales and laterales muscles respectively (Figs. 1, 2, 4, 10). The intertransverse "ligament" (ITL) was just anterior to the intertransverse muscles and had a distinct horizontal and vertical leaf in our dissections (Figs. 2, 4, 9 C, 9 E, 9 G, 10). Its development ranged from a thin membranous to a thick ligamentous structure. The psoas muscle was imme-

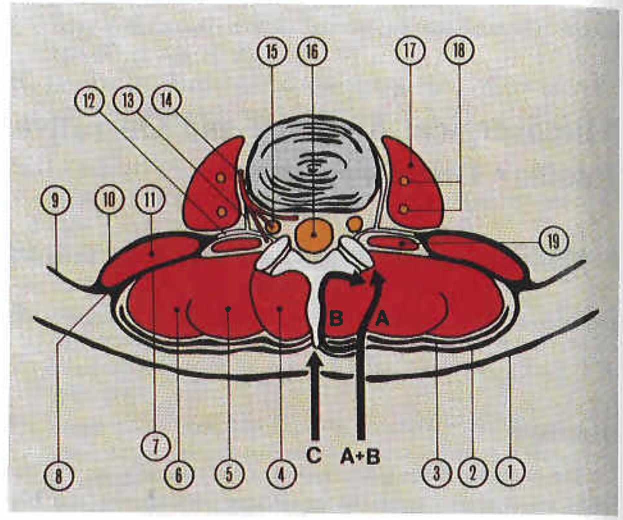


Fig. 2. Axial schematic of the lumbar spine. Skin (*1*), thoracolumbar fascia (*2*), ESA (*3*), multifidus, longissimus and iliocostalis m. (*4* – *6*), lateral raphe (*8*), aponeurosis of transversus abdominis (*9*), quadratus lumborum m. (*11*), intertransverse m. (*19*), horizontal leaf of ITL (*12*), psoas muscle (*17*) with nerve plexi (*18*), emerging nerve (*15*), thecal sac (*16*), Midline approach (*C*), Paramuscular approach (*B*), Transmuscular approach (*A*). The ITL is continuous with the anterior (*10*) and middle (*7*) layer of the thoracolumbar fascia. The lumbar artery- LA (*14*) runs medial to the vertical leaf (*13*) of the ITL, gives off the radicular artery and other branches, and then pierces the horizontal leaf

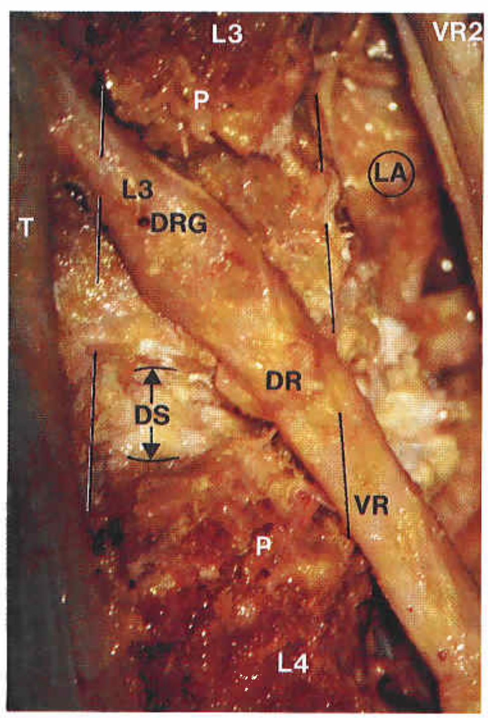


Fig. 3. Right L 3 – 4 LIPC after removal of posterior elements and ligamentum flavum. The pedicles (*P*) form the superior, inferior, medial and lateral borders of the LIPC. The postero-lateral aspect of the vertebral body and disc space (*DS*) from the anterior border. The key to our technique is the exposure of the cranial 1/2 to 2/3 of the LIPC which contains the proximal part of the L 3 DRG (*DRG*) and gives access to the disc space and the herniation. After leavingthe thecal sac (*T*) opposite the inferior border of the L 3 pedicle, the L 3 nerve courses lateral to the L 4 pedicle. L 3 ventral ramus (*VR*), origin of doral ramus (*DR*), L 2 ventral ramus (*VR-2*) after dissection of psoas m., location of lumbar artery (not seen) (*LA*). The medial and lateral "foramina" are at the medial and lateral borders of the LIPC

diately anterior to the horizontal and lateral to the vertical leaf (Figs. 1, 2, 4, 10). The ITL forms 3 compartments: the psoas and the nerve plexi within it-antero-laterally, the LIPC and adjacent region- antero-medially, and the intertransversarii and posterior paraspinal muscles-posteriorly.

The Lumbar Nerves

The nerve roots exited from the thecal sac progressively more cranial in relation to their pedicles from L 1 to S 1 (Figs. 3 and 7 A). A dorsal and ventral "root", separated by a septum but enclosed in a common dural sheath, was found at all levels. The DRG was located within the LIPC immediately inferior to the cranial pedicle (Figs. 3, 9 G, 9 I). The subarachnoid space terminated immediately proximal to the dorsal root ganglion (DRG). The spinal nerve divided within a few millimeters into its larger ventral and smaller dorsal rami near its exit from the LIPC (Figs. 3, 4, 6, 9 G, 9 J, 10). The ventral ramus coursed lateral to the caudal pedicle, where it traversed the vertical leaf of the ITL to enter the psoas muscle (Figs. 3, 4, 6, 7). The sinuvertebral nerve and rami communicantes arose from the proximal portion of the ventral ramus (Fig. 6). Neither of these branches are routinely seen at surgery.

The Lumbar Arteries and Veins

The lumbar artery (LA) coursed between the emerging nerve, medially, and the vertical leaf of the ITL, laterally (Figs. 2, 4, 6, 9 J, 10). In this region it gave off the radicular artery and other proximal branches. Only the radicular artery was systematically dissected in this study. The ventral ramus from the next cranial segment, coursing within the substance of the psoas muscle, was just lateral to the vertical leaf and the LA. After giving off its proximal branches, the LA penetrated the horizontal leaf of the ITL along with the accompanying veins. This penetration site is an important landmark for the lateral limit of the exposure. Veins accompanying the arteries and rich anastomoses of venous plexi were found in the intertransverse space and the LIPC.

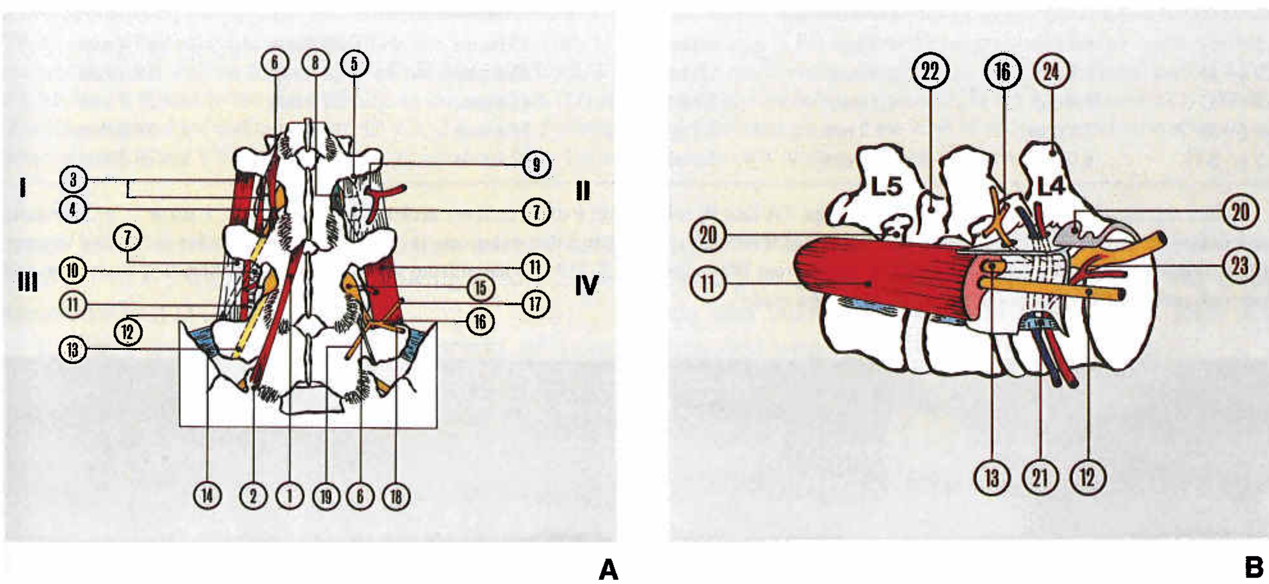


Fig. 4 (A). Posterior view of lumbar spine. Multifidus m. (*1*) mamillary process (*2*). *I.* The medial intertransverse m. (*4*) arises from the accessory process (*5*), the mamillo-accessory "ligament" (*6*) and the mamillary process and attaches to the mamillary process of the vertebrae below. The lateral intertransversii (*3*) course between the TPs lateral ot the operative exposure (Fig. 10). *II.* LA (*9*), horizontal leaf of the ITL (*7*), lateral border of LF (*8*). *III.* After removal of part of horizontal leaf. LA medial to vertical leaf (*10*), exiting (*13*) and cranial ventral rami (*12*) within the psoas muscle (*11*), iliolumbar ligament (*14*). *IV* ITL removed. DRG (*15*), dorsal ramus (*16*) and its lateral (*17*), intermediate (*18*), and medial (*19*) branches. The medial branch passes beneath the mammilo-accessory ligament. These branches innervate the paraspinal muscles, posterior vertebral elements, and skin. (B) Right oblique view. The psoas m. arises from the anterior aspect of TPs (*20*), lateral aspect of intervertebral discs, and the fibro-tendinous arch (*21*) over the lateral concave side of the body (*4*). It courses anterior to the TPs and sacral ala into the pelvis. The exiting ventral ramus is medial to, until piercing to enter the psoas m., the vertical leaf of the ITL. The dorsal ramus pierces the horizontal leaf and trifurcates near the junction of the caudal superior articular process (*22*) and TP. The LA and vein pierce the vertical leaf by passing deep to the arch. Radicular artery (*23*), spinous process (*24*)

The Lateral Interpedicular Compartment and the Course and Relationships of the Lumbar Nerves

Changes in the width, orientation and origin of the lumbar pedicles, in the origin of the transverse processes (TPs), and in the configuration of the vertebral arch lead to important alterations in the course and relationships of the lumbar nerves (Table 1 and Figs. 5, 6, 7, 9 G, 9 I). The lumbar pedicles originated from the vertebral bodies more anterio-laterally from L 1 to L 5 (Fig. 5). Simultaneously, the TPs originated from their pedicles more anteriorly. The horizontal width of the pedicles increased in the caudal direction due to an increase in their diameter and the change in the orientation of their long axis from vertical at L 1 to oblique at L 5 (Fig. 7). The width of the LIPC consequently increased in the caudal direction. The course and orientation of the nerves changed in parallel with the osseous changes (Figs. 6 and 7).

There was an increase in the horizontal and a de-

Table 1. *Lumbar Spine Morphometrics*

	7 A-a	Maximal horizontal pedicle width *****	******	R	7 A-b ***	7 B-c **
L 1 (−2)	4.5 mm	7.2 mm	7.1 mm	7.1 mm	17.5°	8.1 mm
L 2 (−3)	5.5 mm	7.8 mm	7.9 mm	7.8 mm	20.3°	7.8 mm
L 3 (−4)	6.0 mm	9.8 mm	9.6 mm	9.7 mm	29.3°	7.9 mm
L 4 (−5)	10.3 mm	13.2 mm	13.4 mm	13.0 mm	37.0°	6.6 mm
L 5 (−S 1)	14.9 mm	18.5 mm	18.8 mm	18.0 mm	50.5°	2.9 mm

	7 A-c	7 A-d ****	7 A-e	7 B-a	7 B-b	7 B-d *
L 1 (−2)	6.8 mm	1.3 mm	0.3 mm	42.0 mm	20.7 mm	17.4 mm
L 2 (−3)	5.3 mm	2.5 mm	1.0 mm	42.6 mm	23.0 mm	19.1 mm
L 3 (−4)	6.4 mm	1.5 mm	2.7 mm	41.8 mm	27.0 mm	21.1 mm
L 4 (−5)	7.8 mm	− 1.2 mm	4.7 mm	38.8 mm	31.0 mm	24.6 mm
L 5 (−S 1)	6.0 mm	− 3.1 mm	7.1 mm	32.0 mm	38.3 mm	29.0 mm

Values represent average measurements (see Figs. 7 A and B) taken from 6 dried cadaver skeletons, + 8 lumbar CT scans *, + 2 formalin fixed cadavers **, *** 3 formalin fixed and 1 fresh cadaver only. **** calculated value (see text) with negative number indicating location caudal to superior aspect to facet joint, ***** taken from Pfaundler *et al.*[12], ****** taken from direct cadaver morphometric evaluation and from radiographs (R) of cadaver spines by Marchesi *et al.*[17].

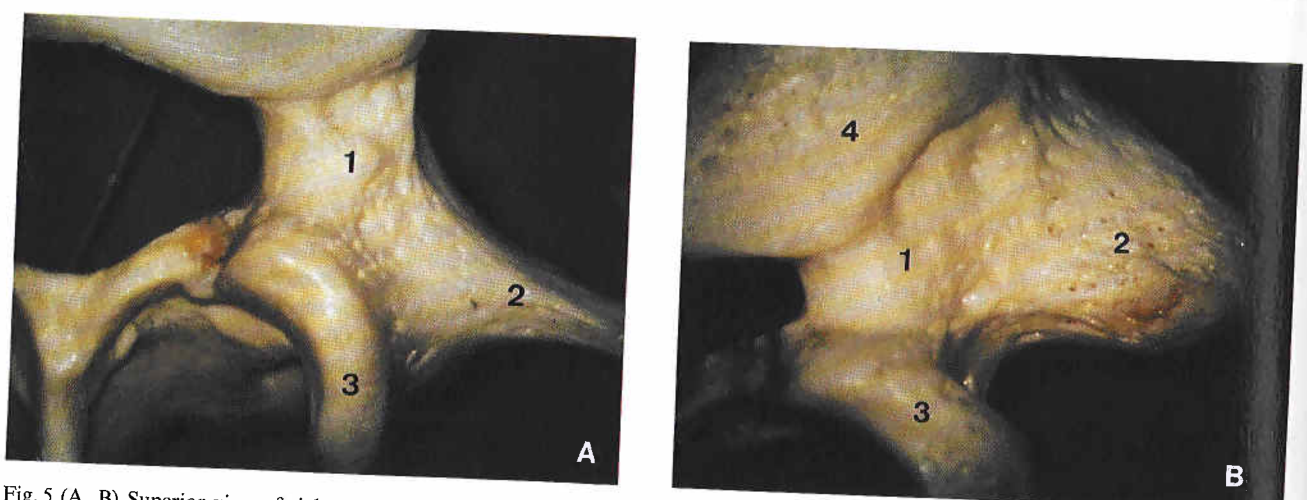
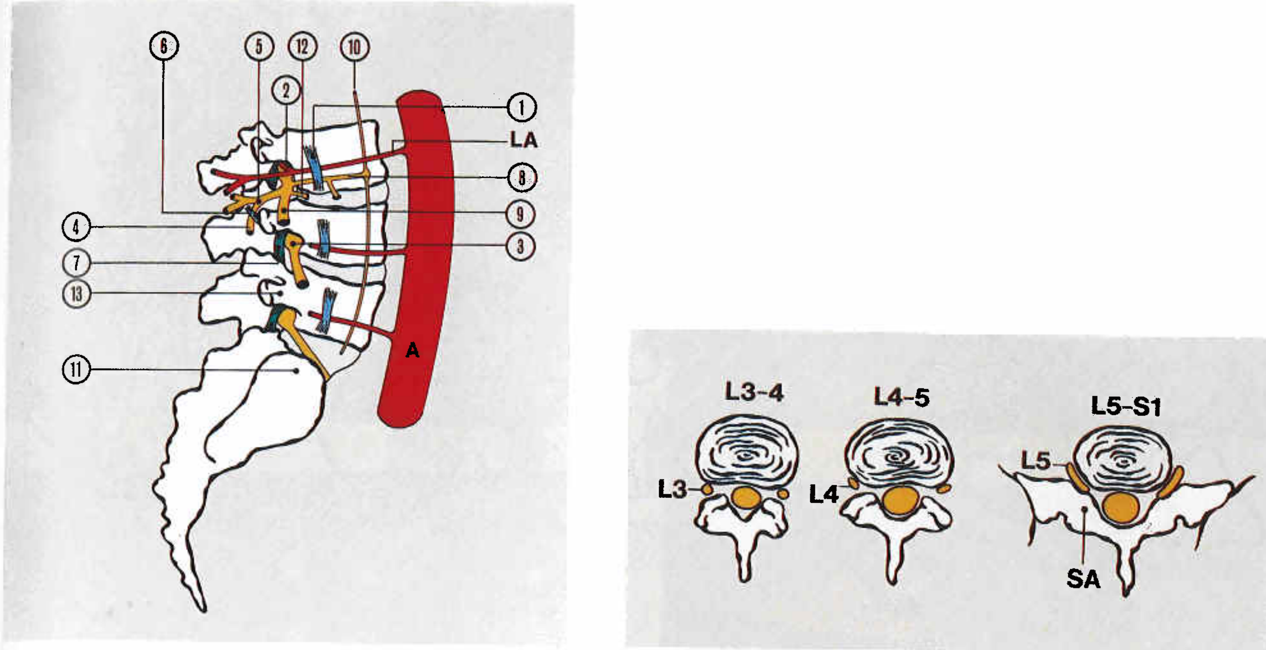


Fig. 5 (A, B) Superior view of right L 3 and L 5 vertebral arch, respectively. Note the greater width and more antero-lateral and broader origin of the L 5 pedicle (*1*). The L 5 TP (*2*) arises together with the pedicle from the postero-lateral aspect of the vertebral body (*4*) while the L 3 TP originates from the posterior aspect of its pedicle adjacent to the origin of the superior articular process (*3*).



A B

Fig. 6 (A) Lateral view of the lumbar spine. The lumbar artey (*LA*) arises from the aorta (*A*) at L 1 − 4 and the median sacral artery at L 5 (not shown) (*4*). Fibrotendinous arcade (*1*) of psoas muscle, radicular artery (*2*), DRG (*3*), medial branch (*4*) of the dorsal ramus (*5*), mamillo-accessory ligament (*6*), lateral shelf of the LF (*7*). The ramus communicans (*8*) connects the ventral ramus (*9*) with the sympathetic chain (*10*). The sinuvertebral nerve (*12*) is a recurrent branch of the ventral ramus which intervates the posterior longitudinal ligament, the intervertebral discs, the adjacent vessels and the anterior dura of the thecal sac[4, 21]. Since the ventral ramus courses anterior to the caudal TP, its sagittal and axial course and relationships are altered due to the changes seen in Fig. 5. Note the progressively greater contact between the ventral ramus and the lateral aspect of the disc from L 3 to L 5. The L 5 ventral ramus, which wraps around the lateral surface of the L 5-S 1 disc, is related to the disc medially, to the sacral ala (*11*) laterally and postero-inferiorly, and to the L 5 TP (*13*) superiorly. (B) The changing relationships and courses of the *L 3, L 4*, and *L 5* ventral rami in the axial plane at the level of the intervertebral disc space are demonstrated. These 3 illustrations were reproductions from the anatomy seen on a lumbar CT scan. Sacral ala (*4*)

crease in the vertical dimensions of the vertebral arch from L 1 to L 5 which had the following effects in the same direction (Fig. 7).

1. There was an increasing proportion of bone within the operative exposure.

2. The distance from the base of the TP to the superior aspect of the facet joint decreased significantly while the distance from the base of the TP to the caudal endplate varied slightly without a distinct pattern. The difference in these two measurements reflects the position of the disc space relative to the overlying facet joint. Its relative positions thereore shifted distally.

3. An increasing amount of the pars interarticularis (isthmus) extended lateral to the medial border of the LIPC to overlie the lateral shelf of the ligamentum flavum (LF). Therefore, an increasing quantitiy of bone had to be removed to expose the superior portion of the LIPC. Due to the diminished working space, additional bone removal was sometimes required from the base of the L 5 TP to gain access to the lateral aspect of the isthmus (Fig. 7). For distal exposure of the L 5 ventral ramus, the medial aspect of the sacral ala and lateral aspect of the L 5-S 1 facet joint was removed with the drill (Figs. 7 and 9 K).

Operative Technique for the ELLDH

Our approach to a L 4-5 ELLDH is presented. The important differences encountered at other levels and with special variants are discussed.

After positioning for routine posterior lumbar surgery a lateral x-ray is taken with a spinal needle placed opposite the superior aspect of the L 4 spinous process, thus marking the midpoint of the 5 − 7 cm skin incision (Fig. 8). The incision will be approximately 3 − 4 cm from the midline. To provide an oblique view, the incision is 1 − 1.5 cm lateral to the facet joint. Thus its distance from the midline, which can be calculated from the CT scan, increases caudally until being limited by the iliac crest at L 5-S 1 (Table 1). The skin, subcutaneous tissue, and posterior layer of thoracolumbar fas-

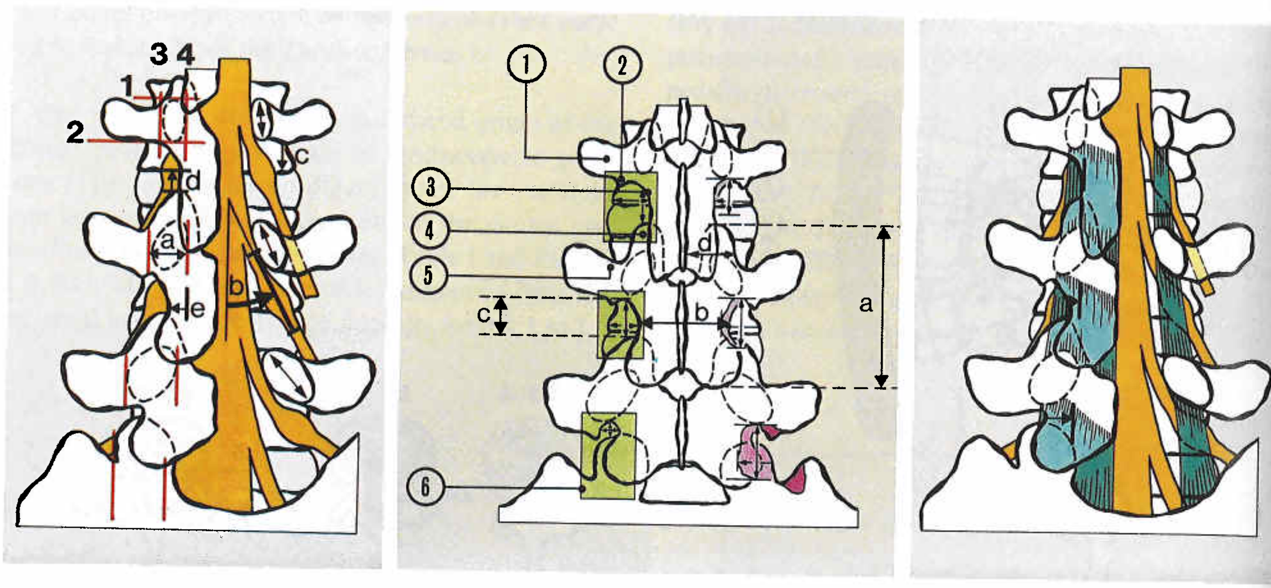


Fig. 7 A. LIPC, pedicle and nerve (coronal plane) alterations. The approximate locations of the pedicle's borders: (*1*) superior- a line drawn perpendicular to the midpoint of the vertical dimension of the facet joint; (*2*) inferior- a line drawn parallel with the inferior aspect of the TP; (*3*) lateral- a line along the lateral aspect of the superior articular process; (*4*) medial- a line drawn perpendicular to midpoint of the transverse dimension of the facet joint. Effective horizontal width (*a*) of pedicle, angle of the "foraminal" segment of the nerve from the vertical (*b*), distance from the base of TP to the caudal endplate (*c*), calculated distance from the superior aspect of the disc space to the superior aspect of the facet joint (*d*), amount of isthmus extending lateral to the medial border of the LIPC (*e*). The change in the orientation of the long axis of the pedicle is seen on the right. This diagram was taken from a angled x-ray and incorrectly shows the distance from the top of the pedicle to the superior endplate of the vertebral body. At all lumbar levels in the cadaver this distance was from 1 – 4 mm and was not increased cranially as implied. (B) Operative exposure (green boxes) and osseous changes in posterior elements. The osseous landmarks are: the medial aspect of the cranial TP (*1*) with its accessory process (*2*), the lateral aspect of the isthmus (*3*) and the supero-lateral portion of the caudal facet joint (*4*). For the uncommon infero-lateral extraforaminal ELLDH, the superior aspect of the caudal TP (*5*) is exposed. The supero-medial aspect of the sacral ala (*6*) is routinely exposed for a L 5-S 1 ELLDH. Note that the exposure is centered over the LIPC and the most medial aspect of the intertransverse space. Maximal vertical (*a*), and minimal horizontal (*b*) dimensions of the posterior arch, distance from the base of the TP to the superior aspect of the facet joint (*c*), distance from the midline to the lateral aspect of the facet joint (*d*). Level dependent bone removal (violet), additional bone removal- see text (dark violet). (C) The lateral shelf of the LF runs from the inferior aspect of the cranial pedicle caudo-laterally to insert along the superior aspect of the pedicle below and thus froms the posterior border of the LIPC covered by a level dependent quantity of bone (arrows)

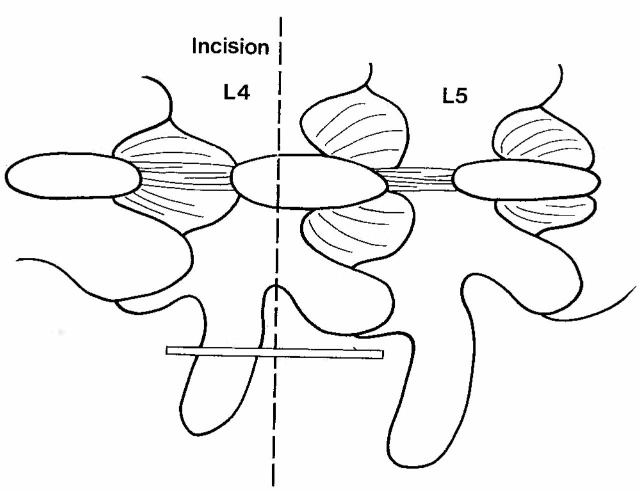
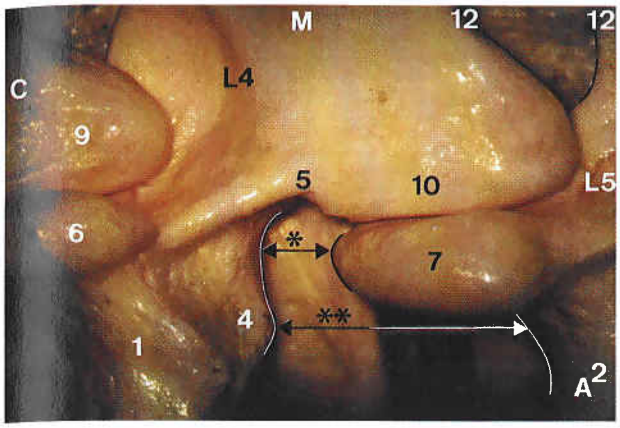
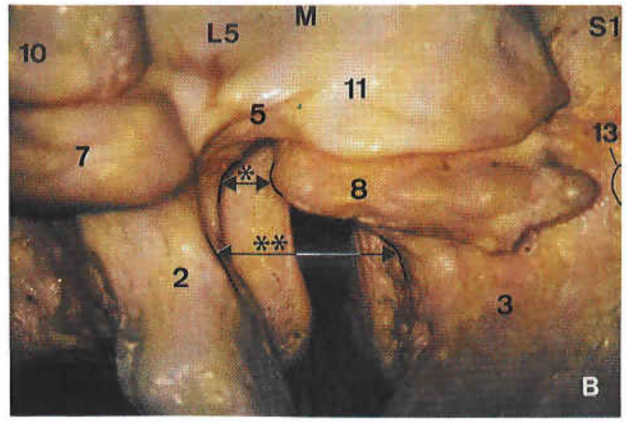


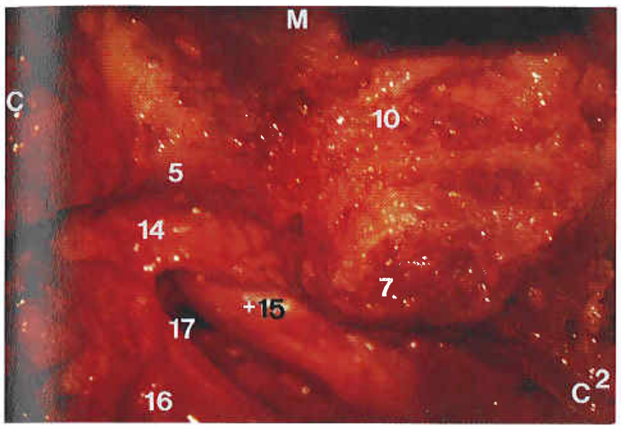
Fig. 8. Skin incision for left L 4 – 5 ELLDH

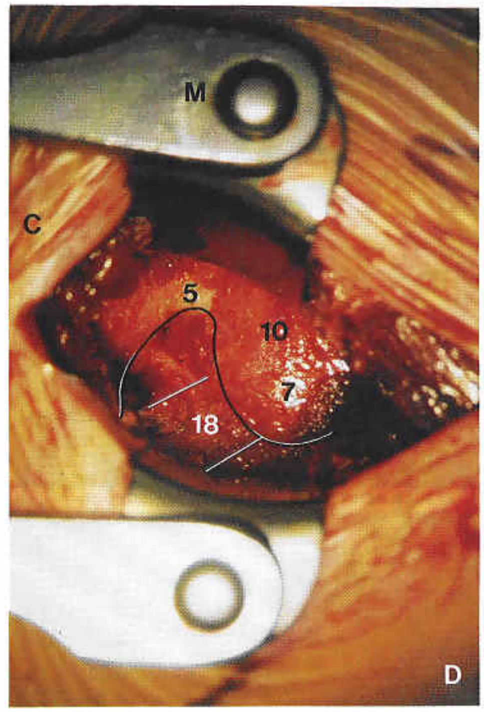
cia are incised revealing, through a thin adipose layer, the ESA.

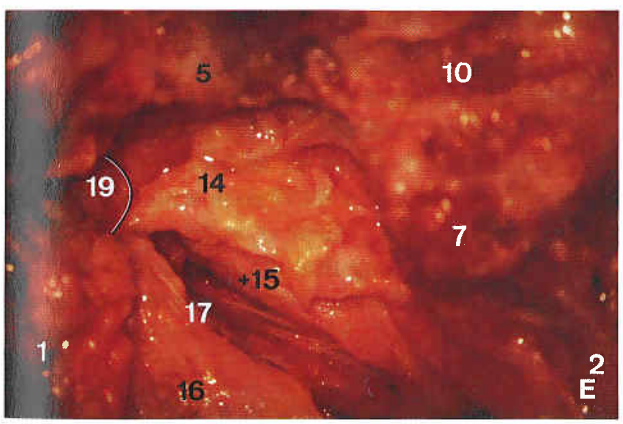
One may proceed via a paramuscular approach or incise the ESA for a transmuscular approach (Fig. 2). The transmuscular approach provides an oblique view with little tissue retraction but, when unaccustomed, is more confusing. Although optional in the upper lumbar spine, it is essential at L 5-S 1 due to the distance from the midline. The paramuscular approach is more familiar but requires a longer incision and greater retraction. This approach is preferable in obese patients in the upper lumbar spine. In the paramuscular approach, the ESA is incised at its attachment to the spinous processes and a subperiosteal dissection of the multifidus is performed. To minimize injury to its capsule, the insertion of the multifidus on the facet joint











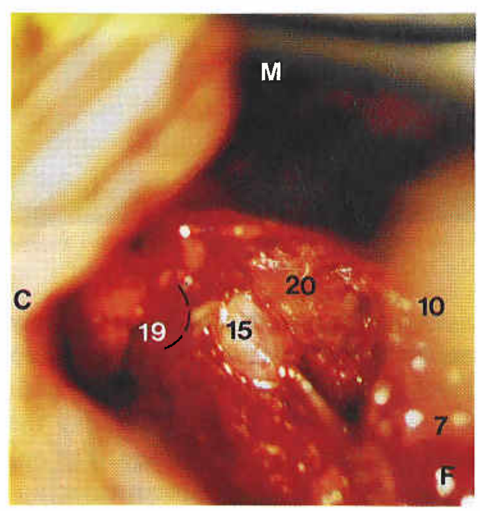


Fig. 9. A–F
Fig. 9. G–K

Fig. 9. G–K

is sharply incised. A self-retaining hemilaminectomy retractor is placed with the tips of its lateral blade deep to longissimus muscle. Retraction proceeds slowly until adequate exposure is achieved to avoid injuring the spinous processes and interspinous ligament. The operation then proceeds as in the transmuscular approach. In the transmuscular approach, dissection is directed medially, beneath the ESA, towards the intermuscular plane between the multifidus and the lumbar longissimus muscles. A fibrous septation usually identifies its location. If there is no distinct plane, one is created by dissecting through the muscles along a path guided by palpation. The plane is enlarged until the osseous landmarks can be palpated in its depths (Fig. 7 B).

Refer to Fig. 9 for the anatomy and sequential steps for a L 4 – 5 and L 5-S 1 ELLDH. The majority of the L 4 – 5 facet joint and the caudal aspect of the L 3 – 4 facet joint will be initially palpable. Further dissection will expose the area of the L 4 isthmus and the medial aspect of the L 4 TP which lie in a deeper plane. A spinal needle is carefully placed superficially in the soft tissues at the junction of the base of the L 4 TP with the isthmus for a lateral radiograph. One must be careful to expose the correct level and location. If one aims too far medially the laminar edges can be confused for the TPs of the intertransverse space or the S 1 dorsal foramen can be confused for the narrow L 5-S 1 intertransverse space (Figs. 9 A, B).

After confirming the level, a Caspar type retractor is placed. The medial blade is placed so that its tips are on the lamina beneath the partially undermined multifidus. A slightly longer lateral blade is placed so that its tips are anterior to the longissimus at the level of the TPs. The differences in the depth of blade placement will help to force the retractor into an oblique position. The operating microscope is now utilized. If part of the multifidus muscle obscures the operative view despite retraction, that portion should be resected. The operative target is the isthmus (Figs. 7, 9, 10). Just lateral to the isthmus, is the medial intertransverse space. The overlying medial intertransverse muscle is often detached during the initial exposure (Figs. 4 and 10 A). The only reason to expose this region is to prevent and control bleeding from branches of the LA and accompanying veins. Avoid any dissection in the intertransverse space lateral to the LA and anterior to the horizontal leaf of the ITL due to the risk of causing troublesome bleeding, and neural and vascular injury (Figs. 2, 4, 10). Extensive dissection of the intertransverse space medial to the LA is unnecessary and also

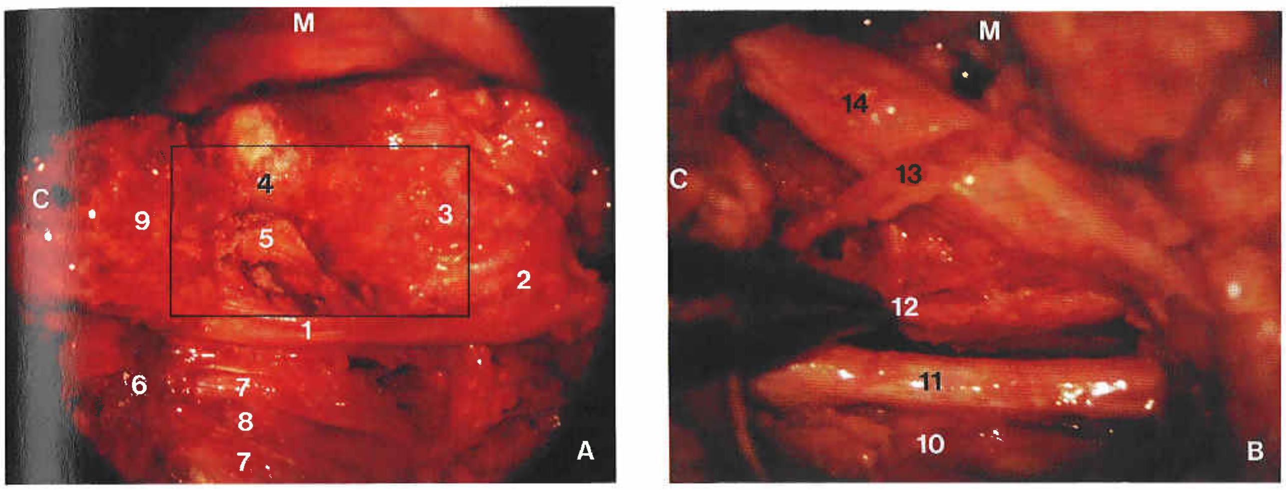


Fig. 10. Cadaver- left L 3 – 4 intertransverse region. Orientation: (*C*) cranial, (*M*) midline. A) Medial intertranverse muscle (*1*), L 4 mamillary process (*2*), L 3- – 4 facet joint (*3*), L 3 isthmus (*4*), lateral border of LF (*5*), accesssory process of TP (*6*), horizontal leaf of ITL (*8*) seen between fibers of lateral intertransverse muscle (*7*), inferior portion of L 2 – 3 facet (*9*). Operative exposure indicated by box. B) After resection of horizontal leaf of ITL and lateral aspect of the LF and dissection within the psoas muscle (*10*), the ventral ramus from the cranial segment (*11*), the vertical leaf (*12*) of the ITL, the LA (*13*), and the emerging nerve (*14*) are seen

Fig. 9. Technique of exposure of LIPC and its contents-operative orientation: midline (*M*), cranial (*C*).
A) and B) Osseous anatomy of dried skeleton. A) Left L 4 – 5. B) Left L 5-S 1. Note the shorter distances from the base of L 5 TP to the superior aspect of the L 5-S 1 facet joint (*) and to the sacral ala (**) compared to L 4 – 5 and the sagittal orientation of the L 4 – 5 facet joint versus a 45 degree orientation at L 5-S 1. L 4 (*1*) & L 5 (*2*) TP, sacral ala (*3*), accessory process (*4*), lateral aspect of isthmus L 4 & L 5 (*5*), superior articular process of L 4 (*6*), L 5 (*7*) & S 1 (*8*), inferior articular process L 3 (*9*). L 4 (*10*), L 5 (*11*), laminar edges L 4 – 5 (*12*), location os S 1 dorsal foramen (*13*). C) Cadaver- after removal of capsule of L 4- – 5 facet joint, medial intertransverse muscle and medial part of horizontal leaf of ITL. Resection of the intertransverse ligament is not part of our technique but it was partially resected for illustrative purposes. Lateral border of LF (*14*), lateral aspect (+) L 4 nerve (*15*), remainder of horizontal (*16*) and vertical (*17*) leaves of ITL. D) Operative case. Same anatomy as C) Osseous structures and medial intertransverse muscle (*18*) outlined. E) Cadaver L 4 – 5 after drilling lateral aspect of isthmus and a small amount of the supero-lateral aspect of facet joint. LF courses caudo-laterally from its attachment ot the inferior aspect of the L 4 pedicle (*19*) the spongiosa of which is a landmark for the bone removal. Lateral border of LF coincides with lateral border of LIPC. F) Operative case after removal of LF. Disc fragment (*20*) displacing DRG posterio-laterally. G) Cadaver- LF excised. DRG just inferior to pedicle. Evacuated disc space (*21*). The dorsal (*22*) and ventral (*23*) rami are not seen at surgery to this extent as the ITL is not routinely resected. The key to our technique is the early exposure of the "intraforaminal" portion of the nerve and then working caudo-laterally as indicated. Note that only the extraforaminal" portion (+) of the nerve is visible prior to LF excision even with resection of the medial aspect of the intertransverse ligament. H) – K) Cadaver L 5-S 1. H) Same anatomy as in B). Lateral border of LF. I) After bone and LF removal. Horizontally oriented L 5 nerve (*24*), the wide and obliquely oriented inferior aspect of the L 5 pedicle (*25*), and L 5-S 1 disc space (*26*). J) Inferio-medial aspect of L 5-S 1 intertransverse region. L 5 dorsal ramus (*27*), LA (*28*) displaced superiorly. K) Medial aspect of sacral ala and lateral aspect of facet joint drilled after sacrificing dorsal ramus for a distal L 5 ventral ramus exposure. Lateral aspect of L 5-S 1 disc space (*26*), L 5 ventral ramus (*29*), and facet articular surfaces (*30*)

potentially dangerous. Inadvertent sacrifice of branches of the dorsal rami may occur prior to their visualization. Regardless, there is no reason to search for them. The use of monopolar cautery in the intertransverse region should be avoided[32].

Next, one must expose the LF to the superior and medial border of the LIPC. Inferiorly, one should expose only enough to provide access to the disc space. The disc space should be approached obliquely from cranially rather than from strictly lateral to preserve as much of the facet joint as possible. Our findings on the approximate location of the borders of the pedicles in the cadaver, allow one to predict the boundaries of the LIPC, the location of the disc space and DRG, the coronal course of the nerve at a given level, and thus to plan the appropriate amount of bone removal (Figs. 7, 9). The exact location of the disc fragment and other conditions such as "foraminal stenosis" and degenerative hypertrophy, seen on the CT scan, will also influence the extent of bone removal[25].

An incision of the soft tissue is made with the electrocautery along the margins of the bone to be removed. The demarcated tissue is removed with curettes and scissors. A high speed drill is used beginning at the isthmus and continuing in an arcuate fashion until the LF is exposed. Drill superiorly until exposing the spongiosa of the inferior aspect of the pedicle and medially to the approximate medial border of the LIPC. Depending on the location of the herniation, as seen on the CT scan, one may not need to drill the isthmus to the medial border of the LIPC at L 5-S 1. There is no specific landmark inferiorly. When drilling remember that the DRG lies immediately inferior to the cranial pedicle, that the course of the nerve changes at different levels and is altered by the herniation, and that the lateral aspect of the L 5 pedicle blends with the medial aspect of TP (Figs. 3, 5, 7, 9).

After excision of the LF and the anterior capsule of the facet joint, with which it blends, with a scalpel or microscissors, a variable quantity of fibro-adipose tissue is seen. Further dissection discloses the dorsal root ganglion which should not be mistaken for the disc fragment. Since the typical foraminal herniation lies anterior and medial to it, the ganglion is frequently displaced posteriorly and laterally (Fig. 9 F). Additional bone can be removed while protecting the nerve. Remove additional LF and isthmus medially with care especially in the upper lumbar spine due to the proximity of the thecal sac (Fig. 3). The disc fragments are located and removed. Since the preoperative course is often long, the fragments may be encased in fibrous connective tissue. We displace the nerve with a microsurgical sucker instead of a nerve retractor. Manipulation of the DRG should be kept to a minimum as it is highly sensitive to mechanical stimulation[4, 13].

Medial to the root, the vertebral body and the disc space can be reached (Figs. 3, 9 G, 9 I). No attempt is made to completely empty the disc space. Rongeurs should be used cautiously as the distance to the anterolaterally related vessels is reduced compared to an interlaminar discectomy[27].

Explore medial and anterior to the root with the nerve hook. Explore proximally between the lateral aspect of the root and the adjacent infero-medial border of the pedicle, as fragments frequently extend in this region. Lateral disection along the distal part of the ganglion and the spinal nerve is avoided due to the risk of injuring the radicular artery and dorsal ramus (Fisg. 2, 4, 6, 9 G). The dorsal ramus is not usually seen, especially in the foraminal type herniation, as it originates within or adjacent to the distal half of the LIPC (Fig. 3). If a more lateral "extraforaminal" fragment is present, it should be searched for by dissecting distally along the medial aspect of the nerve. If the medial aspect of the horizontal leaf of the ITL is the cause of compression it can be incised from medial to lateral while directly protecting the nerve. After completing the disc removal and achieving haemostasis, the ESA and the thoracolumbar fasciae are closed in one layer and the skin and subcutaneous layer are closed separately.

Sharply dissect the overlying soft tissue and resect the interfering branches of the dorsal ramus to expose the superior aspect of the caudal TP, for an inferolateral ELLDH, of the sacral ala, for a distal L 5 ventral ramus compression (Figs. 4 A, 7 B, 9 J, 9 K). Be aware of the vessels accompanying the dorsal ramus (Fig. 6 A). Avoid the monopolar cautery and Kerison type punch in this region due to the risk of secondarily injuring the nerve proximally. The bone should be carefully drilled since there is no LF to protect the underlying ventral ramus.

A combined lateral (first) and interlaminar approach via an enlarged midline incision should be used for the decompression of an ELLDH causing symptomatic compression of the paramedian and "foraminal" roots simultaneously. With proper bone removal the functional integrity of the facet joint and isthmus can be preserved. It may be possible to decompress the paramedian root from the lateral approach in the upper lumbar spine but, due to the increasing width of the LIPC, this is not feasible without sacrifice of the facet joint in the lower lumbar spine.

Discussion

Bogduk and Twomey have provided an excellent and detailed description of the gross anatomy of the paravertebral muscles, fascia, vessels and nerves of the lumbar spine[4]. Our study confirms many of their findings and expands on and clarifies others.

The cross-hatched appearance of the posterior layer of the thoracolumbar fascia has been attributed to its dual derivation from the latissimus dorsi aponeurosis and collagenous fibers running from the spinous processes to the lateral raphe (Figs. 1 and 2)[4]. The longitudinal fibers of the ESA are derived from the caudal tendons of the thoracic erector spinae muscles and insert on the spinous processes, sacrum, and iliac crest[4]. The lumbar longissimus arises in fascicles from the TP and its accessory process and courses caudally, overlying the dorsal surface of the caudal TPs, to insert on the iliac crest[4]. The lumbar iliocostalis arises from the tips of the TPs and courses to the iliac crest lateral to longissimus[4]. Fascicles of the multifidus muscle arise from the spinous processes and laminae and attach to the mamillary processes of caudally located vertebrae, the sacrum, and the iliac crest[4] (Fig. 4).

The anatomy and relationships of the ITL have been variably described in the literature[3, 4, 12, 24, 26]. Our findings of its location, the variability of its development, and its intimate relationships to the adjacent muscles, neural and vascular structures lead us to avoid incising the "intertransverse ligament" for the early exposure of the ELLDH and the nerve as has been described by some authors[18, 19, 28]. We feel that this provides less exposure and entails a more significant risk of neurological injury and intraoperative bleeding than with or technique (Figs. 2, 4, 10). The ITL has been described as a source of neural compression in the absence of an apposing osseous surface[9, 26]. Our findings would support this only if it is well developed. Even in the absence of an apposing surface, a herniation can create significant tension within the nerve due to the presence of connective tissue bands which attach it to the pedicles, posterior longitudinal ligament and facet joint capsule[4, 8, 12, 24, 32]. Either of these sources of neural compromise can be treated with our technique.

The iliolumbar ligament is classically described as arising from the tip of the L 5 TP and inserting on the ilium (Fig. 4 A)[4, 12]. We have observed in some clinical cases a ligament that arises from the lateral aspect of the L 5 isthmus and courses transversely across the narrow intertransverse space towards the iliac crest. In contrast to the classical definition, Ray calls this the "iliolumbar ligament" and feels that if it is large and well developed it may be a source of neural compression[25].

The level dependent site of origin of the root from the thecal sac which we observed has been previously described[24]. This is important to consider when attempting to dissect within the axilla of the root. The dorsal and ventral "roots" each have their own pia-arachnoid membranes and subarachnoid space but are enclosed in a common dural sheath[12, 20]. The subarachnoid space terminates as the pia-arachnoid of the proximal root becomes incorporated as the endoneurium and perineurium of the spinal nerve. The site of termination has been described at various locations but finding it consistently proximal to the DRG in our material may explain the low yield with myelography since the ELLDH usually causes compression at or distal to the DRG[1, 9, 12, 19, 28, 32]. The lumbar DRG is most commonly within the LIPC but it may lie proximal, intraspinal, or distal, "extraforaminal" to it[11]. Variability of its position may be a source of confusion at surgery.

The proximal lumbar artery (LA) gives off three branches that enter the LIPC- the anterior and posterior spinal canal branches, and the radicular artery- and branches that pass distally with and supply the ventral and dorsal rami and adjacent paraspinal muscles (Figs . 2, 4, 6)[4, 7, 12, 16]. The radicular artery at some levels gives rise to a medullary artery which travels within the root to the conus medullaris[4, 7]. Anastomosis between the internal and external vertebral venous plexi occurs at the LIPC. The plexi and veins can be a troublesome source of bleeding within the LIPC and the intertransverse space.

The anatomy amd terminology of the intervertebral foramen have been previously evaluated[2, 4, 5, 6, 22, 24]. We feel that the best descriptive term for this region is the lateral interpedicular compartment- one not previously used. Pfaundler *et al.*, have described the changes in the anatomy of the lumbar pedicles and intervertebral foramen and discussed the concept of a "horizontal pedicle width"[22]. The morphometric measurements performed on the dried cadaver spines in this study are subject to error because of the loss of the in vivo relationships of soft tissues; possible loss of bone content during preparation and with ageing of the specimens, and because of the lack of information concerning the age, origin, and medical conditions of the subjects. This may explain the quantitative differences in the values for the width of the pedicles in this study compared to those of Pfaudler *et al.* and Marchesi *et al.*[17,22]. Regardless, the measurements were intended to demonstrate a trend rather than being interpreted for their actual values. The effects of the osseous and neural changes on the pathophysiology and surgery for ELLDH were examined in our study. In summary, the upper lumbar nerves (L 1-3) run at an acute angle from the vertical in thier brief "intraforaminal" course and are entirely posterior to the lateral aspect of the disc space in both their "intra"- and "extraforaminal" course (Figs. 3, 6, 9 G). In contrast, the L 5 nerve has an oblique, long "intraforaminal" course and in its "extraforaminal" course is intimately related to the lateral aspect of the L 5-S 1 disc space (Figs. 6, 9 I, 9 K). Therefore, a purely lateral "extraforaminal" disc herniation in the upper lumbar spine will be too far anterior to compress the nerve while the same herniation can result in significant compression at the caudal levels (Fig. 6). This anatomical finding supports our clinical impression that herniations which are primarily lateral to the intervertebral disc space more frequently require surgery in the lower than in the upper frequently require surgery in the lower then in the upper lumbar spine. The shape of the LIPC at L 5-S 1 conforms to a canal or tube while it is more like a "foramen" at the other lumbar levels[22]. The long "intraforaminal" course of the L 5 root together with the diminsihed cross-sectional area of its LIPC increase the risk of root compression from ELLDH, foraminal stenosis and "pedicular kinking"[4, 15, 22]. Entrapment of the L 5 ventral ramus between the L 5 TP and the sacral ala, "the far out syndrome", has been described in patients with degenerative scoliosis and isthmic spondylolisthesis[31]. Ray feels that a more common site of compression of the distal L 5 ventral ramus is between the lateral aspect of the disc or adjacent osteophytes, medially, and the sacral ala, postero-laterally[25, 32]. The course and relationships of the L 5 nerve in our study reveal its vulnerability to clinically significant compression at these distal sites and provide a technique for treatment.

The changing anatomy also affects the surgical procedure. The amount of bone removal necessary increases in the caudal direction. The L 5-S 1 level is the most difficult due to its deep location, small working space and more complex relationships of the L 5 root.

The advantages of our lateral microsurgical technique are: 1) the direct approach to the lesion; 2) the preservation of the functional anatomy of the facet joint and isthmus; 3) the avoidance of neurological injury by the early identification of the foraminal segment of the nerve. The technique can be sied for other lesions in this region including foraminal stenosis and lateral tumours.

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